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Encapsulation Characteristic of Bougainvillea (*Bougainvillea glabra*) Dye Extract in Comparison of Maltodextrin and Carrageenan

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Abstract

Bougainvillea flower is recognized as food coloring agent due to the presence of betacyanin compounds. The extraction of these compounds is followed by a subsequent process for encapsulation. Therefore, this research aimed to determine the effect of maltodextrin and carrageenan on encapsulation characteristics of bougainvillea flower dye extract and obtain the best ratio. Encapsulation was carried out with the ratio of maltodextrin and carrageenan, namely 10:0 (MC1), 9.5:0.5 (MC2), 9:1 (MC3), 8.5:1.5 (MC4), 8:2 (MC5) and 7.5:2.5 (MC6). The results showed that maltodextrin and carrageenan ratio significantly affected the amendment, moisture content, solubility, brightness level (L^*), redness level (a^*), yellowness level (b^*), total betacyanin, surface betacyanin and encapsulation efficiency. Based on the test, the effectiveness index to produce the best treatment was MC3 with characteristics of amendment, moisture content, solubility, brightness level (L^*), redness level (a^*), yellowness level (b^*), total betacyanin, surface betacyanin and encapsulation efficiency at 91.61 ± 0.34, 6.53 ± 0.22, 87.35 ± 1.90 %, 80.43 ± 1.37, 20.37 ± 0.49, 20.73 ± 0.40, 246.99 ± 2.70, 35.76 ± 0.46 mg/100 g and 85.52 ± 0.09 %, respectively. The encapsulated formulation of bougainvillea flower extract with maltodextrin and carrageenan in a balanced ratio can be used as an alternative to provide natural coloring in food processing.

Keywords: Bougainvillea, Encapsulation, Maltodextrin, Carrageenan, Natural dye

Introduction

Color is one of the crucial aspects in consumer acceptance of a product. Furthermore, it serves as an indicator of quality and freshness or ripeness in food [1]. Natural dye is pigment obtained from plants or animals, primarily found in roots, barks, leaves, bracts, flowers, skins and shells of plants [2]. This dye has been used as food coloring and is considered safer than synthetic dye [3]. A natural color pigment used as a dye is betacyanin, which is widely adopted in food products. This color pigment is extensively used for coloring purposes and also possesses antioxidant properties.

Bougainvillea *(Bougainvillea glabra*), also known as Paper flower, is one of the ornamental plants from South America but is easily found in Indonesia [4,5]. The colors of bougainvillea flower vary, including red, yellow, orange, white and purple [6]. In the research by Nurhasanah and Anggita [7], phytochemical screening results showed that the flower contained alkaloids, saponins, tannins, phenolics, flavonoids, triterpenoids and glycosides. The purple-red corolla of bougainvillea flower contained betacyanin pigment used as natural dye [8]. Meanwhile, betacyanin is a water-soluble compound, making water a suitable solvent for the extraction process [9]. This compound is a plant pigment that imparts red to purplish colors [2,10].

Extraction is the initial stage in analyzing bioactive compounds from plant materials [11]. The extract of bougainvillea flower pigment can be obtained through maceration. This method is used to extract or draw desired compounds from a solution or solid by immersing the material to be extracted. The advantage of the method lies in its simple procedure and equipment. This method can be used to avoid evaporation, which may cause damage to betacyanin compound components in the material. Sepahpour *et al.* [12]; Fikri *et al*. [13] reported that the type of solvent and extraction time could influence the results. Previous research showed that achieving the most well-defined extract of natural bougainvillea flower pigment included using a solvent mixture comprised of 96 % ethanol and 20 % citric acid. The extraction process is conducted at a temperature of 30 °C, with a modified maceration time of 36 h [8] and the result of bougainvillea flower maceration is in the form of a thick extract.

Concentrated extracts are often labile, requiring transformation into a solid form. Another limitation of liquid-form pigment extract preparations is the short shelf life and less stable color, necessitating protection for the compounds in the liquid pigment extract formulation [14]. A technology used for this purpose is encapsulation, which includes the entrapment of a core material. The aim is to protect sensitive components and reduce the degradation of active compounds in the material [15]. This process can shield active ingredients from adverse environmental effects such as oxidation and hydrolysis damage, evaporation, or heat degradation, resulting in a longer shelf life and improved stability of the active ingredients. Factors influencing encapsulation are based on the nature of the core material and the type of encapsulant used [16].

Coating materials are substances that serve as coatings for the active ingredient in the microencapsulation process [17]. Previous research results indicated that the combination of gum arabic and maltodextrin was more effective in protecting the active ingredient compared to other materials [18]. The use of gum Arabic is considered expensive and has limited availability. Therefore, there is a need for alternative materials to replace gum Arabic used in combination to create a more effective coating with better emulsification capabilities [19]. The types of encapsulants to be used in this research are maltodextrin and carrageenan.

Maltodextrin is used as a coating material to form emulsions due to low viscosity [20]. This material has the property of easy solubility in cold water [21]. However, it has poor emulsification capabilities, requiring a combination with other materials to enhance the emulsification ability of encapsulation [22]. Carrageenan can be used as a coating material in encapsulation process due to the pseudoplastic characteristics, causing the microcapsules to have a round shape and a smooth surface. Additionally, the material possesses desirable properties as an emulsifier which is safe for consumption and biodegradable [19].

Several examinations on the comparison of coating materials for encapsulation process have been conducted previously. Purnomo *et al.* [19] stated that the ratio combination of maltodextrin, carrageenan, and whey as coating materials significantly influenced the microencapsulation of natural dye from teak leaves. Antares *et al.* [23] showed that the ratio of encapsulating materials, maltodextrin and carrageenan, significantly affected the characteristics of encapsulation of pandan fruit dye extract. Vagisvari *et al.* [24] indicated that the optimal treatment for producing encapsulated natural dye extract from cassava leaves was to use a maltodextrin-carrageenan ratio of 90:10 % and a concentration of 5 %.

Based on previous results, the comparison of encapsulating materials can influence the characteristics of the process. Therefore, it is necessary to determine the effect of the maltodextrin and carrageenan ratio on encapsulation characteristics of bougainvillea flower pigment extract. This research identifies the optimal maltodextrin and carrageenan ratio for obtaining encapsulation of bougainvillea flower pigment extract.

Materials and methods

Materials & equipment

The raw materials used in this research include bougainvillea flower with a violet-red color, obtained from Abiansemal Subdistrict, Badung Regency, Bali (**Figures 1(A) - 1(B)**). The chemicals adopted comprised 96 % ethanol (Bratachem), 20 % citric acid (Lansida), distilled water, citrate-phosphate buffer pH 5 (Chem-Mix Pratama) and encapsulating materials such as maltodextrin (Lansida, DE 10-12) and carrageenan (Lansida).

The equipment used in this research consisted of an extraction flask, magnetic hotplate stirrer, vortex (Barnsteadl Thermolyne), drying oven (Blue M), blender (Philips), knife, separating funnel, 60, 40 mesh sieve, Whatman filter paper No.1, rotary evaporator (IKA RV 10), spectrophotometry (UV-Vis) thermo, analytical balance (Shimadzu), color reader (PCE-CSM 1) and Scanning Electron Microscope (InTouchScope™ JSM-IT200).

Preparation of bougainvillea extract

The process of preparing bougainvillea flower extract follows the procedure outlined by Tanone [8] with modifications. Fresh bougainvillea flower was manually sorted, separating flower from stem. Subsequently, flower was washed with running water to remove any dirt or insects before drying using a dehydrator at a temperature of 50 ± 2 °C for 24 h with a moisture content of 7.84 %. The dried sample was crushed using a blender and sieved through a 60-mesh sieve (**Figure 1(C)**).

Making bougainvillea flower dye extract

The extraction process refers to the procedure carried out by Tanone [8] using the maceration method. A total of 50 g was weighed and 500 mL solvent (250 mL 96 % ethanol: 250 mL 20 % citric acid) was added. The sample was macerated for 48 h at 30 °C and stirred manually for 3 min every 6 h. Furthermore, it was filtered using coarse filter paper to obtain filtrate I and 100 mL of solvent was added to obtain filtrate II. Filtrates I and II were mixed and filtered using Whatman filter paper No.1. Filtrate was evaporated using a rotary evaporator at 50 °C with a pressure of 100 mbar to remove the solvent in the extract. Therefore, solvent did not drip and a thick extract of bougainvillea flowers obtained was stored in a bottle (**Figure 1(D)**).

Making bougainvillea flower dye extract encapsulates

Encapsulation of bougainvillea flower dye extract was performed using the thin layer drying method, following the procedures outlined by García-Salinas and Ariza [2]; Yogaswara *et al.* [25], with some modifications. Encapsulation solution was prepared in a volume of 100 mL by weighing maltodextrin and carrageenan, each at 10 % of the solution, according to the specified treatment. Meanwhile, distilled water was added to achieve a total volume of 100 mL. Approximately 1 % of encapsulant solution was combined with bougainvillea dye extract and homogenized using a homogenizer for 30 min. The resulting solution was poured into a petri dish lined with baking paper, creating a layer with a thickness of 3 mm. The solution was dried in an oven at a temperature of 50 ± 2 °C until it could be easily removed from the petri dish, which took approximately 13 h. The resulting encapsulate was crushed using a mortar and sieved through a 40-mesh sieve (**Figure 1(E)**).

Figure 1 Bougainvillea flower (A), dried flowers (B), bougainvillea flower powder (C), flower dye extract (D) and microencapsulate (E).

Analytical method

Determination od yield

Testing of the encapsulate yield of bougainvillea flower dye extract was carried out according to Sudarmadji *et al.* [26] which was calculated based on a comparison between the weight of the resulting encapsulate powder with the weight of the encapsulant and the weight of the extract initial raw materials used. Calculation of yield (%) was calculated using the following Eq. (1):

$$R = BE/BEE \quad (1)$$

Description: R = yield (%), BE = encapsulate weight (g) and BEE = weight of encapsulant and extract (g).

Water content

Determination of water content was based on the difference in sample weight before and after drying. The ground sample was weighed ± 2 g (initial sample weight) into a cup. Then dried in an oven at 105 °C for 4 h or until it reaches constant weight. After that it was cooled using a desiccator for ± 15 min and weighed. The drying and weighing process was carried out until it reaches a constant weight [27]. Calculation of water content can be calculated using the following Eq. (2):

$$\text{Water content (\%)} = (\text{Initial sample weight} - \text{Final sample weight})/(\text{Initial sample weight})\times 100\ \% \quad (2)$$

Solubility

A sample of 1 g (a) was dissolved in 50 mL of distilled water. Whatman paper No. 1 dried in an oven at 105 °C for 30 min then weighed (b). Next, the solution was filtered using Whatman paper No. 1. Whatman paper and filtered residue were dried in the oven at 105 °C for 3 h. Then cooled in a desiccator and weighed (c). The solubility value was expressed as a percentage of the weight of the residue that cannot pass through the Whatman paper [28]. Calculation formula solubility can be determined using Eq. (3):

$$\text{Solubility in water (\%)} = (100\ \% - (c - b))/((100 - EC)/100 \times a) \times 100\ \% \quad (3)$$

Description: a = sample weight, b = weight of filter paper, c = weight of filter paper and sample, EC = encapsulate content.

Color intensity system L^*, a^* and b^*

Color intensity measurements were carried out using a color reader. Color intensity was measured by attaching the receptor tip to the beaker containing the sample and then pressing the target button on the color reader. The L^* button shows lightness, the a^* button shows green to red and the b^* button shows blue to yellow [29].

Total betacyanin levels

Determination of total betacyanin levels using the modified Eder method [30]. A total of 0.1 g of encapsulated bougainvillea flower extract was dissolved in citrate-phosphate buffer solvent pH 5 to 5 mL. Next, it was homogenized using a vortex and then left for 15 min. Then the absorbance value was measured using a UV-Vis spectrophotometer with wavelengths of 537 and 600 nm. The absorbance value was calculated as A = 1.095×(537 - 600). Next, total betacyanin levels were determined using the following Eqs. (4) - (5):

$$\text{Total betacyanin content (mg/L)} = (A \times MW \times DF \times 1{,}000)/(\varepsilon \times L) \quad (4)$$

Description: A = absorbance, MW = molecular weight of betacyanin 550 g/mol, DF = dilution factor, ε = molar extension coefficient 60,000 L/mol·cm and L = cuvette thickness (1 cm).

$$\text{Total betacyanin content (mg/100g)} = (X \times V \times 1{,}000 \times 100)/W \quad (5)$$

Description: X = initial equation concentration (mg/L), V = volume (L), W = sample weight (mg), and MW = molecular weight of betacyanin 550 g/mol.

Surface betacyanin levels

Determination of surface betacyanin levels using the modified Eder method [30]. A total of 1 g of encapsulated bougainvillea flower extract was dissolved in 10 mL of distilled water. Next, it was homogenized using a vortex then centrifuged for 10 min at a speed of 3,000 rpm. After that, the pure supernatant was collected and then the absorbance value was measured using a UV-Vis spectrophotometer with wavelengths of 537 and 600 nm. The absorbance value was calculated as A = 1.095×(537 - 600). Next, total betacyanin levels were determined using the following Eqs. (6) - (7):

$$\text{Surface betacyanin content (mg/L)} = (A \times MW \times DF \times 1{,}000)/(\varepsilon \times L) \quad (6)$$

Description: A = absorbance, MW = molecular weight of betacyanin 550 g/mol, DF = dilution factor, ε = molar extension coefficient 60,000 L/mol·cm and L = cuvette thickness (1 cm).

$$\text{Surface betacyanin content (mg/100 g)} = (X \times V \times 1{,}000 \times 100)/W \quad (7)$$

Description: X = initial equation concentration (mg/L), V = volume (L), W = sample weight (mg) and MW = molecular weight of betacyanin 550 g/mol.

Encapsulation efficiency

The encapsulation efficiency of bougainvillea flower dye extract can be calculated using the following Eq. (8) [31]:

$$EE = (\text{Total Betacyanin} - \text{Surface Betacyanin})/(\text{Total Betacyanin}) \times 100\ \% \quad (8)$$

Morphology testing

The encapsulated morphology was measured and using Scanning Electron Microscopy (SEM, InTouchScope™ JSM-IT200). The samples were coated with gold, placed on a support and photographed at magnifications 50×, 500×, 1,000× and 2,500× [32].

Statistical analysis

The objective data obtained has been tested using analysis of variance (ANOVA) and if the treatment has an effect on the observed variables, then it has been continued with the Duncan's Multiple Range Test (DMRT). All the tests were performed in triplicate, and the obtained data were expressed as mean and standard deviation.

Results and discussion

Encapsulate yield

The diversity analysis shows that encapsulation comparison treatment has a significant effect ($p \leq 0.01$) on the yield of encapsulated bougainvillea flower color extract, as seen in **Table 1**.

Table 1 The average yield (%) value of bougainvillea flower dye extract in encapsulant comparison treatment.

Comparison of Maltodextrin (M) and Carrageenan (C)	Rendement (%)
MC1 (10:0)	89.39 ± 0.20^{e}
MC2 (9.5:0.5)	90.88 ± 0.11^{d}
MC3 (9:1)	91.61 ± 0.34^{c}
MC4 (8.5:1.5)	92.18 ± 0.05^{b}
MC5 (8:2)	92.86 ± 0.07^{a}
MC6 (7.5:2.5)	93.16 ± 0.05^{a}

Description: Different letters behind the average value indicate a very significant difference ($p \leq 0.01$).

The highest average yield values were obtained in MC6 at 93.16 ± 0.05 %, which was not significantly different from MC5 at 92.86 ± 0.07 %. However, this value is significantly different from MC1 at 89.39 ± 0.20 % and the high yield is attributed to the addition of carrageenan. This compound has a high molecular weight and is capable of forming a gel in water, thereby increasing the solution viscosity. The increase in viscosity also affects the rise in total dissolved solids, resulting in a higher yield. This is supported by the statement from Masters [17] that the total solids content influences the resulting yield. Similarly, Vagisvari *et al.* [24] showed that the yield of encapsulating cassava leaf dye extract with a maltodextrin and carrageenan comparison treatment increased with concentration.

Moisture content

The diversity analysis results indicate that the comparison treatment has a very significant effect ($p \leq 0.01$) on moisture content of encapsulated bougainvillea flower color extract and the average values can be seen in **Table 2**.

Table 1 The average moisture content (%) value of bougainvillea flower dye extract in encapsulant comparison treatment.

Comparison of Maltodextrin (M) and Carrageenan (C)	Moisture content (%)
MC1 (10:0)	5.86 ± 0.05^{e}
MC2 (9.5:0.5)	6.10 ± 0.19^{d}
MC3 (9:1)	6.53 ± 0.22^{c}
MC4 (8.5:1.5)	6.75 ± 0.11^{b}
MC5 (8:2)	6.91 ± 0.07^{ab}
MC6 (7.5:2.5)	7.03 ± 0.03^{a}

Description: Different letters behind the average value indicate a very significant difference ($p \leq 0.01$).

The highest average moisture content values were obtained in MC6 at 7.03 ± 0.03 %, which was not significantly different from MC5 at 6.91 ± 0.07 % but different from MC1 at 5.86 ± 0.05 %. Therefore, the concentration of carrageenan is directly proportional to moisture content. Romenda *et al*. [33] stated that factors influencing moisture content included inherent product properties such as the presence of ions with hygroscopic characteristics. According to Vagisvari *et al*. [24], an increase in moisture content occurs with the increasing concentration of carrageenan.

Solubility

Encapsulant comparison treatment had a very significant effect ($p \leq 0.01$) on the solubility of the bougainvillea flower dye extract. The average solubility value of bougainvillea flower dye extract encapsulation can be seen in **Table 3**.

Table 2 The average solubility (%) value of bougainvillea flower dye extract in encapsulant comparison treatment.

Comparison of Maltodextrin (M) and Carrageenan (C)	Solubility (%)
MC1 (10:0)	94.24 ± 0.36[a]
MC2 (9.5:0.5)	91.60 ± 2.88[a]
MC3 (9:1)	87.35 ± 1.90[bc]
MC4 (8.5:1.5)	85.93 ± 1.09[c]
MC5 (8:2)	69.72 ± 3.36[de]
MC6 (7.5:2.5)	66.61 ± 1.09[e]

Description: Different letters behind the average value indicate a very significant difference ($p \leq 0.01$).

The highest average solubility values were obtained in MC1 at 94.24 ± 0.36 %, which was not significantly different from MC2 at 91.60 ± 2.88 % but different from MC6 at 66.61 ± 1.09 %. The results show that the higher the concentration of carrageenan, the lower the solubility of encapsulate. This is because carrageenan can form a gel in water when a hot solution becomes cold. The formation process is thermoreversible since the gel can melt when heated and reform when cooled [34,35]. Vagisvari *et al*. [24] also reported similar results, stating that solubility decreases with the addition of carrageenan concentration.

Color intensity L^*, a^* and b^*

The diversity analysis shows that encapsulation comparison treatment has a very significant effect ($p \leq 0.01$) on the brightness level (L^*), redness level (a^*) and yellowness level (b^*) of encapsulated bougainvillea flower color extract, as seen in **Table 4**.

Table 3 The average color intensity value of bougainvillea flower dye extract in encapsulant comparison treatment.

Comparison of Maltodextrin (M) and Carrageenan (C)	L^*	a^*	b^*
MC1 (10:0)	84.37 ± 1.05[a]	18.1 ± 0.53[d]	18.97 ± 0.46[f]
MC2 (9.5:0.5)	81.13 ± 1.27[bc]	20.27 ± 0.95[c]	20.27 ± 0.40[e]
MC3 (9:1)	80.43 ± 1.37[cd]	20.37 ± 0.49[c]	20.73 ± 0.40[de]
MC4 (8.5:1.5)	79.40 ± 1.15[cde]	20.83 ± 0.42[c]	21.90 ± 0.44[c]
MC5 (8:2)	78.57 ± 0.32[e]	21.07 ± 1.12[bc]	22.03 ± 0.42[bc]
MC6 (7.5:2.5)	78.20 ± 0.66[e]	23.63 ± 2.29[a]	22.90 ± 0.46[a]

Description: Different letters behind the average value in the same column indicate a very significant difference ($p < 0.01$).

The highest and lowest average brightness levels were obtained in MC1 and MC6 at 84.37 ± 1.05 and 78.20 ± 0.66 %. The highest and lowest redness levels (a^*) were obtained in MC6 and MC1 at 23.63 ± 2.29 and 18.1 ± 0.53 %. Meanwhile, the highest yellowness levels (b^*) were obtained in MC6 and MC1 at 22.90 ± 0.46 and 18.97 ± 0.46 %, respectively.

The results showed that encapsulant comparison treatment had a very significant effect ($p \leq 0.01$) on brightness (L^*), redness (a^*) and yellowness (b^*) levels of bougainvillea flower dye extract encapsulates. A high level of brightness indicates a lower total betacyanin content in encapsulate. The white color of maltodextrin can increase the brightness level of encapsulate. Meanwhile, Wartini and Ganda-Putra [36] stated that the brightness level of encapsulate increased with the concentration of maltodextrin. Vagisvari *et al.* [24] also reported that there was a decrease in the brightness level as the concentration of carrageenan was increased. Redness level is influenced by the total betacyanin content in encapsulated bougainvillea flower dye extract. Betacyanin plays a role in providing a red color, and the high content increases redness level. This is because carrageenan has excellent emulsification properties, leading to the formation of a matrix during encapsulation process to protect betacyanin compounds. Therefore, the concentration of carrageenan is directly proportional toredness level. Vagisvari *et al*. [24] reported that encapsulation ratios of 85:15, 90:10 and 95:5 resulted in redness levels of 2.5, 2.3 and 1.9, respectively.

The yellowness level is influenced by the increase in carrageenan concentration. This is because carrageenan tends to have a whitish-yellowish color. Conversely, maltodextrin has a white color, which affects encapsulate, resulting in a low yellowness level. This shows a direct relationship between the concentration of carrageenan and the yellowness level in encapsulated bougainvillea flower color extract. Vagisvari *et al*. [24] reported an increase in yellowness levels with encapsulation ratios of 85:15, 90:10 and 95:5 at 19.2, 18.7 and 17.4, respectively.

Betacyanin total

Encapsulant comparison treatment had a very significant effect ($p \leq 0.01$) on the total betacyanin of bougainvillea flower coloring extract, as seen in **Table 5**.

Table 4 The average total betacyanin (mg/100 g) value of bougainvillea flower dye extract in encapsulant comparison treatment.

Comparison Maltodextrin (M) and Carrageenan (C)	Total betacyanin (mg/100 g)
MC1 (10:0)	222.24 ± 0.63^{d}
MC2 (9.5:0.5)	228.69 ± 4.43^{cd}
MC3 (9:1)	246.99 ± 2.70^{a}
MC4 (8.5:1.5)	240.15 ± 3.27^{b}
MC5 (8:2)	231.81 ± 5.74^{c}
MC6 (7.5:2.5)	225.72 ± 4.17^{cd}

Description: Different letters behind the average value indicate a very significant difference ($p \leq 0.01$).

The highest and lowest average total betacyanin values were obtained in MC3 and MC1 at 246.99 ± 2.70 and 222.24 ± 0.63 mg/100 g, respectively. A high total betacyanin content indicates that encapsulation process is occurring maximally. The purpose is to protect the core material from factors that can degrade the quality of the substance. The combination of appropriate encapsulation material ratios coats the active components more effectively. The highest total betacyanin content was in MC3. This is because maltodextrin can form a film and has strong binding properties but poor emulsification. The addition of carrageenan can trap and protect the active ingredients during the drying process since the compound has good emulsifying properties. Therefore, the combination of encapsulation materials, maltodextrin and carrageenan, can form a strong protective matrix around the core compound. This is supported by Antares *et al.* [23] on the characteristics of encapsulated pandan fruit dye extract using maltodextrin and carrageenan as coatings with ratio of 9:1.

Surface betacyanin

The diversity analysis indicates that encapsulant ratio treatment significantly influences of surface betacyanin ($p \leq 0.01$) of encapsulated bougainvillea flower dye extract, as presented in **Table 6**.

Table 5 The average surface betacyanin values (mg/100 g) of bougainvillea flower dye extract in encapsulant ratio treatment.

Maltodextrin (M) and Carrageenan (C) Ratio	Surface Betacyanin (mg/100 g)
MC1 (10:0)	39.51 ± 0.42^{a}
MC2 (9.5:0.5)	36.58 ± 0.69^{b}
MC3 (9:1)	35.76 ± 0.46^{bc}
MC4 (8.5:1.5)	35.16 ± 0.60^{cd}
MC5 (8:2)	34.60 ± 0.23^{de}
MC6 (7.5:2.5)	33.84 ± 0.18^{e}

Description: Different letters behind the average values show a very significant difference ($p \leq 0.01$).

The highest and lowest average surface betacyanin values are obtained in MC1 and MC6 at 39.51 ± 0.42 and 33.84 ± 0.18 mg/100 g, respectively. Surface betacyanin is located outside the capsule, indicating suboptimal encapsulation processes. In this research, MC6 results in the lowest values due to the combination of the coating materials. Maltodextrin shows a strong capability to form a matrix structure, aided by the combination with carrageenan. The formation of a strong protective matrix around the core material ensures effective protection.

Increased carrageenan concentration can lead to the formation of a good emulsion, resulting in a low amount of surface betacyanin. This is attributed to the absence of carrageenan as a strong and stable emulsifier, while maltodextrin has poor properties, preventing maximal encapsulation. According to Naz *et al*. [37], low surface betacyanin values correlate with increased carrageenan concentration.

Encapsulation efficiency

Encapsulant ratio treatment significantly influences the efficiency ($p \leq 0.01$) of bougainvillea flower dye extract, as presented in **Table 7**.

Table 6 The average encapsulation efficiency values (%) of bougainvillea flower dye extract in encapsulant ratio treatment.

Maltodextrin (M) and Carrageenan (C) Ratio	Encapsulation Efficiency (%)
MC1 (10:0)	82.22 ± 0.17^{c}
MC2 (9.5:0.5)	84.00 ± 0.19^{b}
MC3 (9:1)	85.52 ± 0.09^{a}
MC4 (8.5:1.5)	85.36 ± 0.40^{a}
MC5 (8:2)	85.07 ± 0.47^{a}
MC6 (7.5:2.5)	85.01 ± 0.20^{ab}

Description: Different letters behind the average values indicate a very significant difference ($p \leq 0.01$).

The highest average encapsulation efficiency value is obtained in MC3 and MC1 at 85.52 ± 0.09 and 82.22 ± 0.17 %. High encapsulation efficiency values indicate greater protection of betacyanin in bougainvillea flower dye extract. The addition of carrageenan leads to increased encapsulation efficiency values, signifying optimal processes. This is attributed to carrageenan ability to bind and protect the active ingredients during the drying process. Naz *et al.* [37] stated that high encapsulation efficiency values correlated with increased carrageenan concentration.

Effectiveness index

The effectiveness index test considers 9 variables, including yield, moisture content, solubility, brightness (L^*), redness (a^*), yellowness (b^*) levels, total betacyanin, surface betacyanin and encapsulation efficiency. Based on the analysis, MC3 has the highest effectiveness index value of 0.66 [31].

Encapsulate morphology

Scanning Electron Microscope (SEM) can be used to determine the surface morphology of materials and is known as an additional method to monitor the formation of inclusion complexes, as presented in **Figures 2 - 10**.

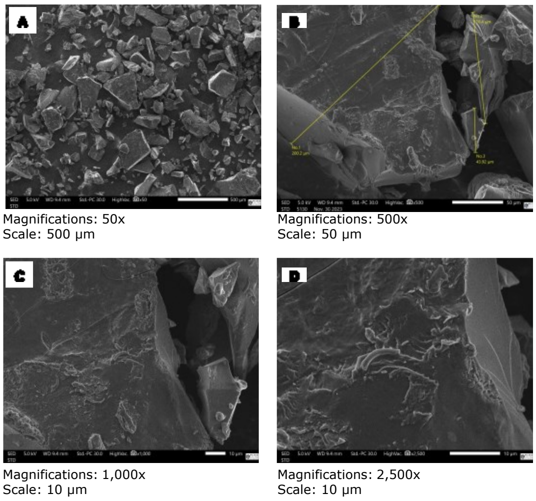

Figure 2 SEM micrographs of encapsulated natural bougainvillea flower dye extract with 5 % maltodextrin treatment at magnifications 50× (A), 500× (B), 1,000× (C) and 2,500× (D).

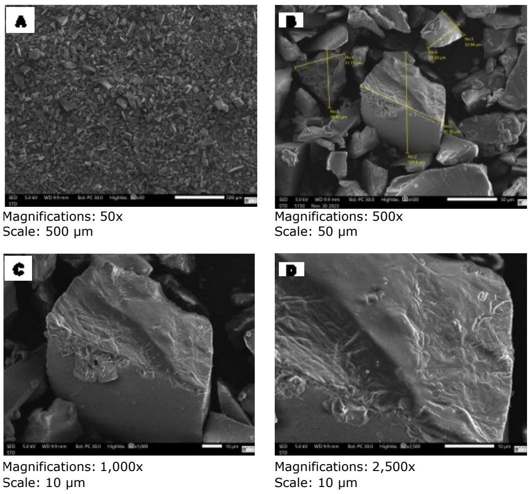

Figure 3 SEM micrographs of encapsulated natural bougainvillea flower dye extract with 5 % gum arabic treatment at magnifications 50× (A), 500× (B), 1,000× (C) and 2,500× (D).

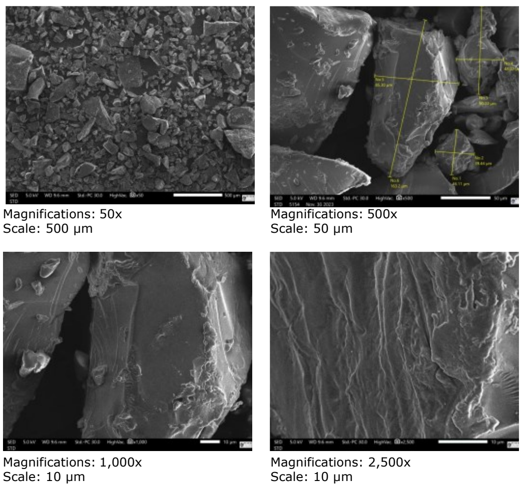

Figure 4 SEM micrographs of encapsulated natural bougainvillea flower dye extract with maltodextrin:gum arabic (1:2) 5 % treatment at magnifications 50× (A), 500× (B), 1,000× (C) and 2,500× (D).

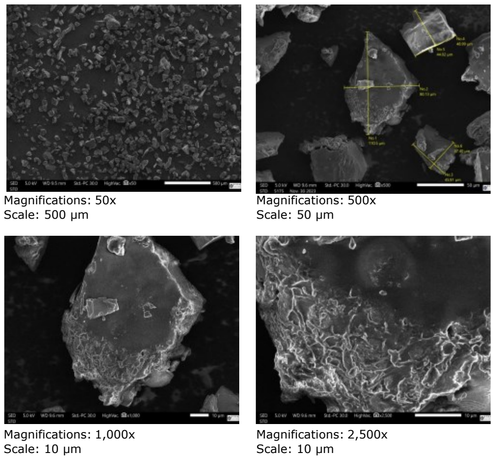

Figure 5 SEM micrographs of encapsulated natural bougainvillea flower dye extract with gelatin:maltodextrin (1:2) 5 % treatment at magnifications 50× (A), 500× (B), 1,000× (C) and 2,500× (D).

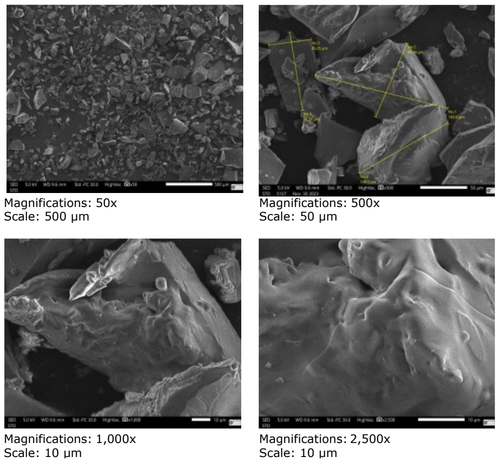

Figure 6 SEM micrographs of encapsulated natural bougainvillea flower dye extract with maltodextrin:carrageenan (9.5:0.5) 5 % treatment at magnifications 50× (A), 500× (B), 1,000× (C) and 2,500× (D).

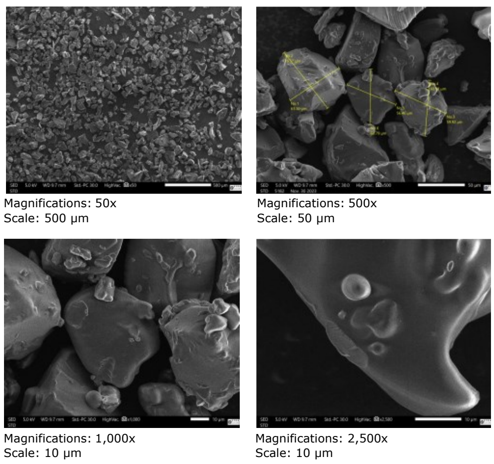

Figure 7 SEM micrographs of encapsulated natural bougainvillea flower dye extract with maltodextrin: carrageenan (9:1) 5 % treatment at magnifications 50× (A), 500× (B), 1,000× (C) and 2,500× (D).

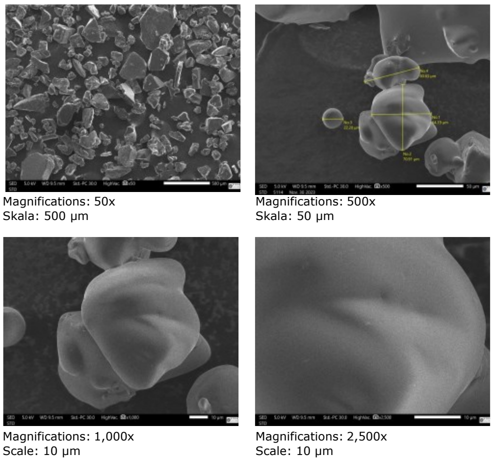

Figure 8 SEM micrographs of encapsulated natural bougainvillea flower dye extract with maltodextrin:carrageenan (8.5:1.5) 5 % treatment at magnifications 50× (A), 500× (B), 1,000× (C) and 2,500× (D).

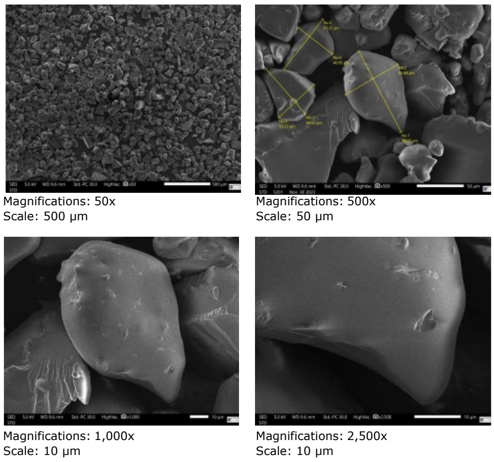

Figure 9 SEM micrographs of encapsulated natural bougainvillea flower dye extract with maltodextrin:carrageenan (8:2) 5 % treatment at magnifications 50× (A), 500× (B), 1,000× (C) and 2,500× (D).

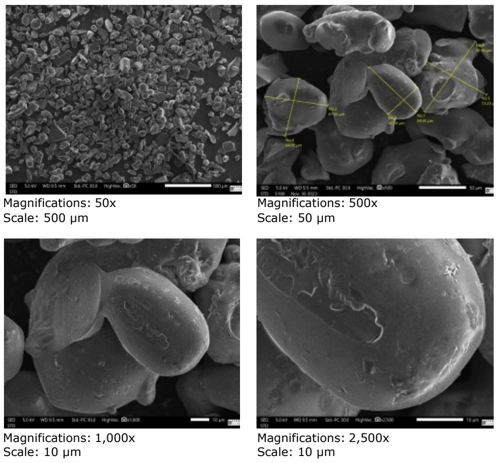

Figure 10 SEM micrographs of encapsulated natural bougainvillea flower dye extract with maltodextrin:carrageenan (7.5:2.5) 5 % treatment at magnifications 50× (A), 500× (B), 1,000× (C) and 2,500× (D).

Figures 2 - 10 depict SEM micrographs of encapsulated bougainvillea flower dye extract at magnifications of 50×, 500×, 1,000× and 2,500×. Microcapsules are expected to have a spherical shape with a uniform and smooth coating, minimal cracks and signs of rupture [25,39,40]. However, the figures show that each encapsulated bougainvillea flower dye extract shows uneven shapes and sizes. The irregularity is attributed to the varying layers of materials used as wall formers. Similar observations were reported by Budihartini [41] regarding the irregular size morphology of microcapsules containing black rice bran dye extract. Escobar-Avello *et al.* [42] reported that encapsulation of phenolic compounds from sugarcane extract in hydroxypropyl beta-cyclodextrin and maltodextrin also resulted in uneven and irregular sizes.

Figures 2 - **6** show irregular and slightly coarser crystal shapes. The use of carrageenan, as depicted in **Figures 7** - **10**, shows an elongated oval shape with a smoother surface. The greater the proportion of carrageenan, the more uniform and smooth the surface becomes. The addition is effective in capturing and protecting active ingredients during the drying process due to the excellent emulsifying properties. Therefore, the combination of maltodextrin and carrageenan can form a strong protective matrix around the core compounds. Similar results were observed by Sansone *et al*. [43], which proposed double-sided MD-pectin as a more suitable carrier for extract compared to maltodextrin by providing physical protection for polyphenols.

Conclusions

In conclusion, the treatment of maltodextrin and carrageenan ratio significantly was reported to influence yield, moisture content, solubility, brightness (L^*), redness (a^*), yellowness (b^*) levels, total betacyanin, surface betacyanin and encapsulation efficiency. The optimal treatment for producing encapsulated natural bougainvillea flower dye extract was MC3, with characteristics of yield, moisture content, solubility, brightness level (L^*), redness level (a^*), yellowness level (b^*), total betacyanin, surface betacyanin and encapsulation efficiency at 91.61 ± 0.34, 6.53 ± 0.22, 87.35 ± 1.90 %, 80.43 ± 1.37, 20.37 ± 0.49, 20.73 ± 0.40, 246.99 ± 2.70, 35.76 ± 0.46 mg/100 g and 85.52 ± 0.09 %, respectively. The formulation of bougainvillea flower extract with maltodextrin and carrageenan in an appropriate ratio can be used as a potential natural coloring alternative in functional food processing.

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